A Multi-Beam IFE Research Facility: T-STAR

Slides presented to DOE IFE Community Workshop

21 February 2022

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LaserNetUS

FOCUSED ENERGY Inc.

TECHNISCHE UNIVERSITÄT DARMSTADT

A number of basic science issues relevant to IFE could be addressed with a high energy multi-beam laser

Examples include

1) Study of LPI and CBET effects in 2ω and 3ω drive beams
- Examine LPI in in hot spot and fast ignition relevant drive pulses
- Examine effects of increased bandwidth
- Explore possibility of STUD pulses for LPI mitigation
- Study CBET in multiple overlapped beams

2) Hydro drive pressure, efficiency and instabilities
- High repetition rate studies of direct-drive relevant situations

3) Study of proton acceleration efficiency
- Examine scaling toward multi-kJ picosecond pulse drive
- Examine pulse duration effects (with eye toward increasing pulse duration)
- Examine effects of overlapping multiple picosecond beams on the acceleration foil

4) Study of hot electron generation
- Conversion efficiency at high drive energies
- Hot electron transport (cone in shell targets)

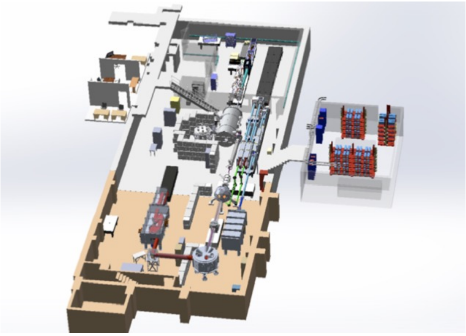
5) Study proton and electron stopping power in pre heated and pre compressed plasmas

6) Advanced diagnostic development for IFE experiments at larger facilities like Omega or NIF
- X-ray or proton backlighters and probes
- Particle diagnostics
- Rep-rated diagnostics

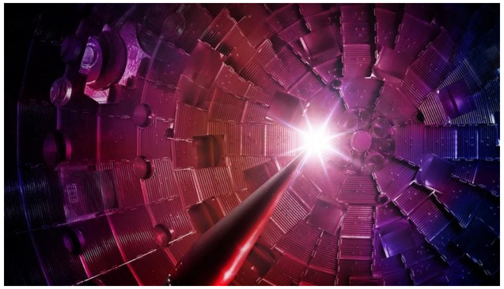
Multi-beam, multi-kJ laser with modest (~shot/min) rep. rate would complement the large ICF machines and help propel study of some of the key physics issues specific to IFE

There is now an opportunity to build a multi-beam, multi-kJ research laser for IFE and basic HED relevant research

Opportunity exists because of three converging developments:

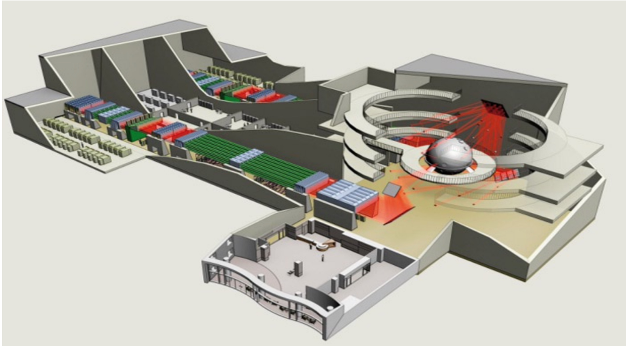


1) *Texas Petawatt facility has been allocated additional high-bay space and TPW is in need of upgrades (rep. rate, multiple beams etc.)*



2) *New national interest in IFE with recent high profile NIF results and the possibility of a new IFE Program at FES*

3) *Significant private investment money is becoming available to propel IFE through start-up companies*



> *Consequently, we are proposing the construction of a 4-beam laser with rep. rate in the UT TPW high bay for IFE and HED related research through the LaserNetUS network*

We are developing a technical plan to commercialize IFE by the mid 2030s, with a goal of attempting ignition by the end of the decade

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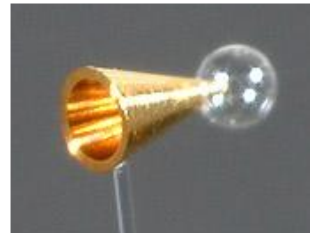
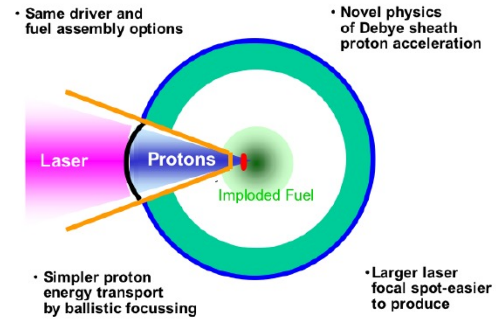
- ***Basic approach chosen is to utilize direct drive implosion with 2ω light and ignite by proton fast ignition***





IFE Phase 1: Test facility and studies

Study most important physics
→ Hydro- eff. and LPI control with 2ω drive
→ proton acceleration with multiple PW beams (10% efficiency goal)

IFE Phase 2: SUPER -NOVA facility. *Ignition*

Study integrated compression/proton heating
→ Cryo-targets
→ proton acceleration with cone-in-shell target

IFE R&D
• 10 Hz diode-pumped Laser module devel
• Mass production target fab
• First wall materials and reactor design

IFE Phase 3a: QUASAR Diode-pumped power plant demo

IFE Phase 3b: High gain

Rep-rated power plant development

IFE Phase 3c: Power demo

IFE Power plant deployment

Prime Movers Lab

A-ROD CORP

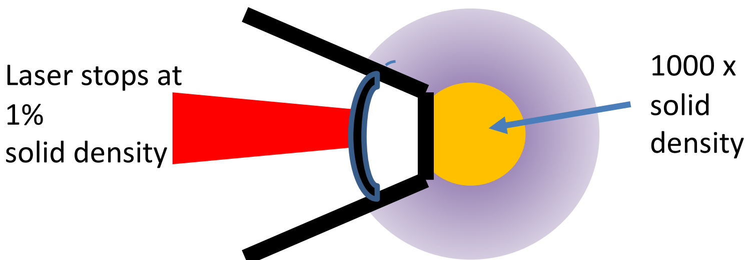
Telosa

Experimental proof of the scaling behavior of our approach | Way to ignition and self-sustaining combustion | Capital market

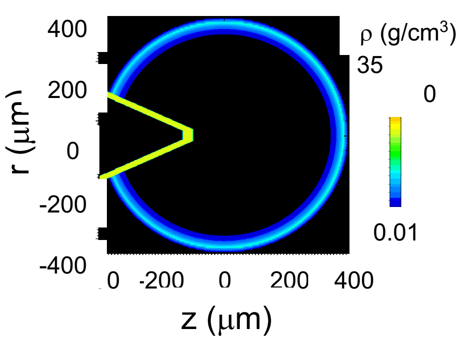
2021 2022 2023 2024 2026 2028 2030 2035 2040

The PFI approach is based on an extensive body of experimental and computation work

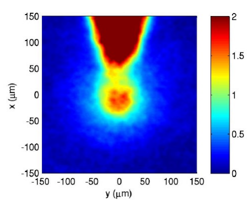
Challenge: Energy must be delivered to the dense fuel



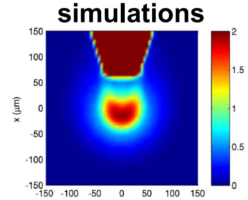
Experiment (2)



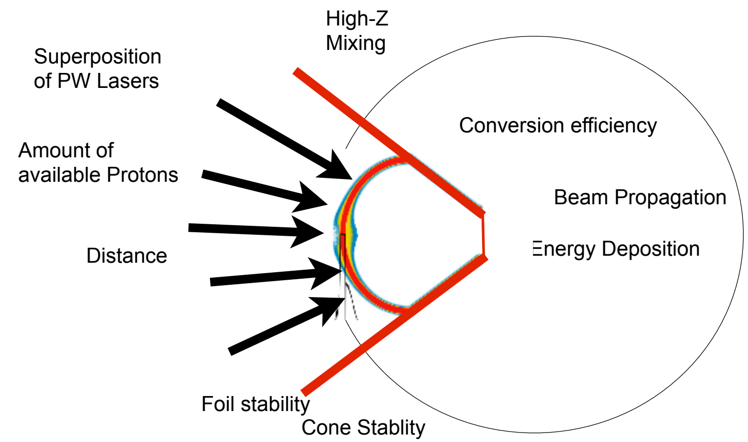
(1)

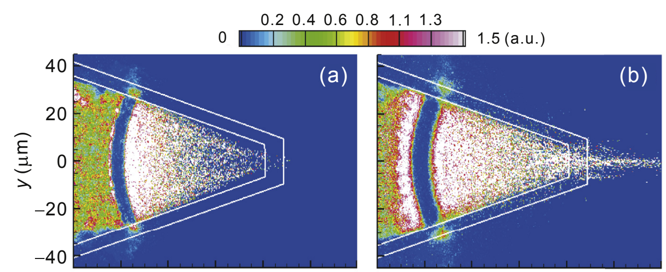


DRACO/Spect3D simulations



We have addressed the key topics in proton fast ignition



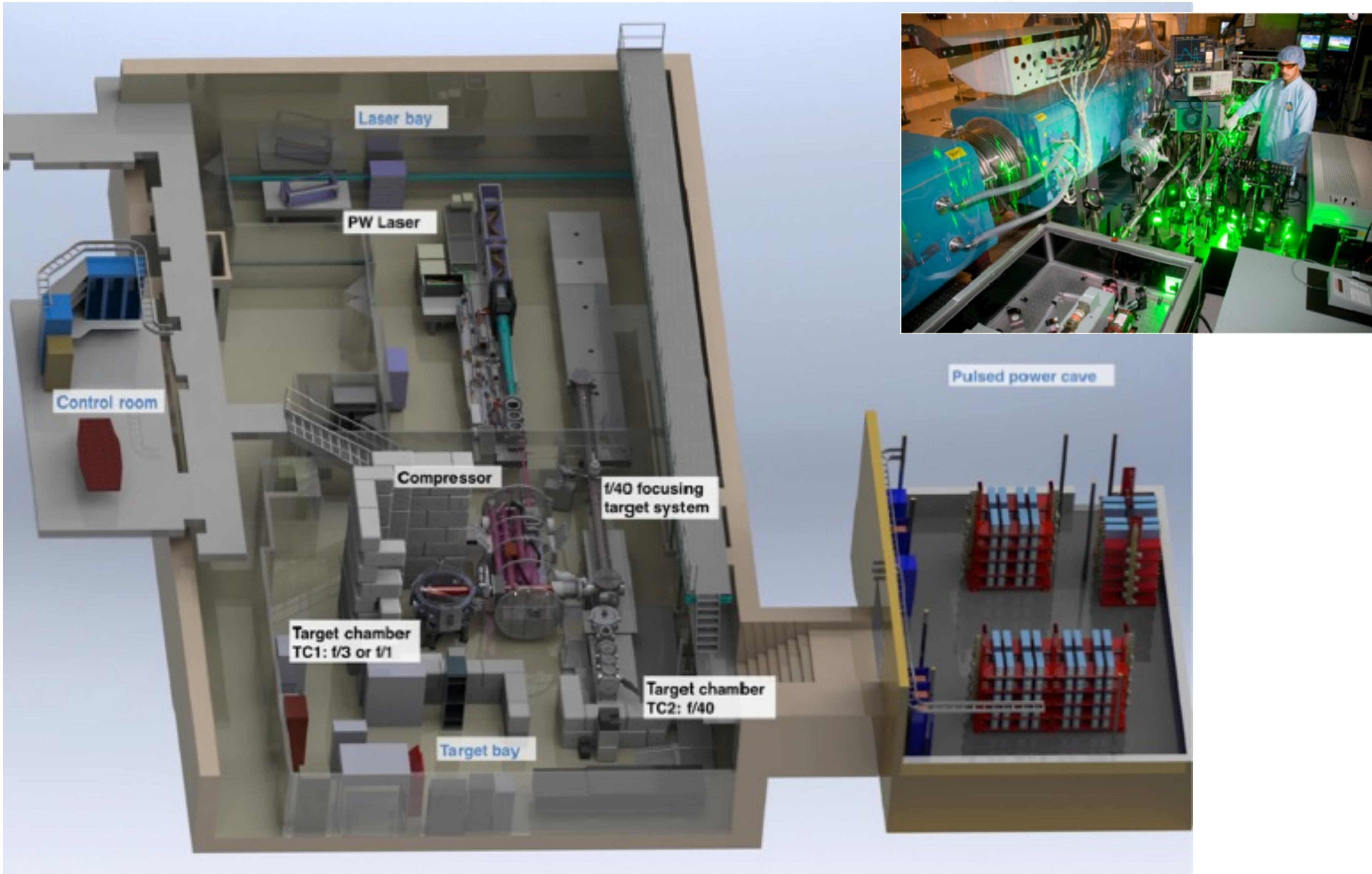


Energy density of the proton beam a) 1ps b) 1.5ps

[1]J.J. Honrubia et al., On intense proton beams and transport in hollow cones, Matter and Radiation at Extremes 2, 28, 2017

[2]W. Theobald et al., 54th Meeting APS-DPP, 2012

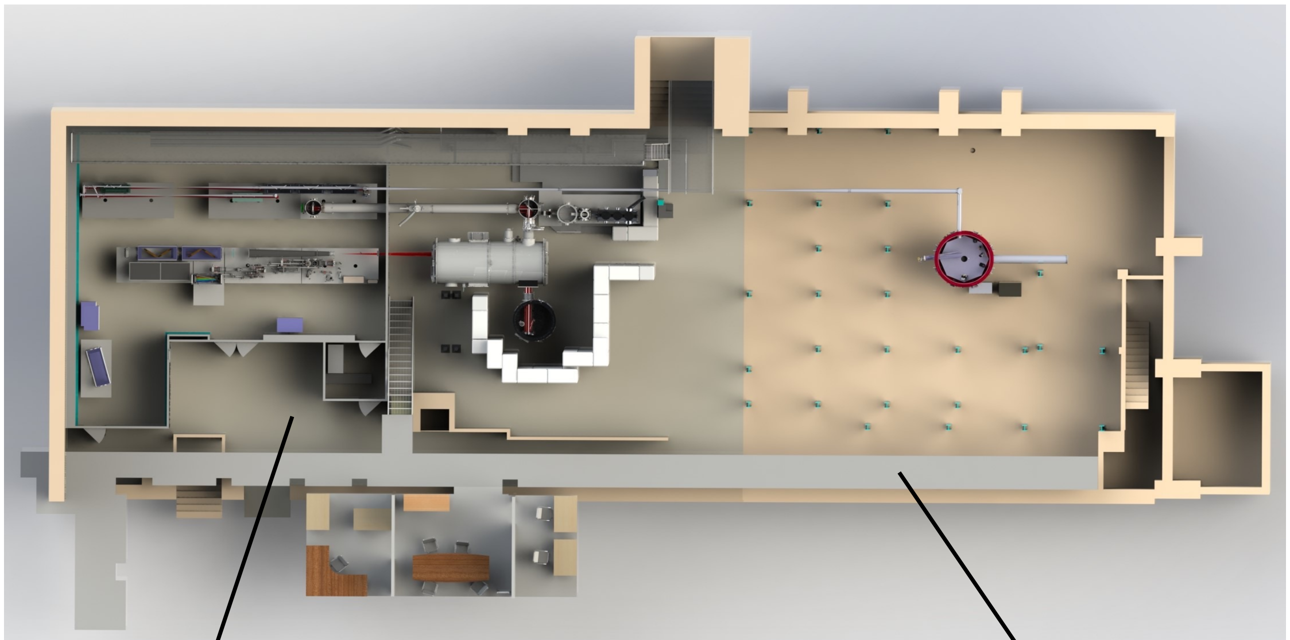
The Texas Petawatt Laser is presently operating in part of an underground high bay on the U. Texas campus



The TPW is a member of the LaserNetUS network and user access is granted through this network

We now have additional high bay space to permit the construction of a multi-beam research laser

Texas Petawatt laser high bay

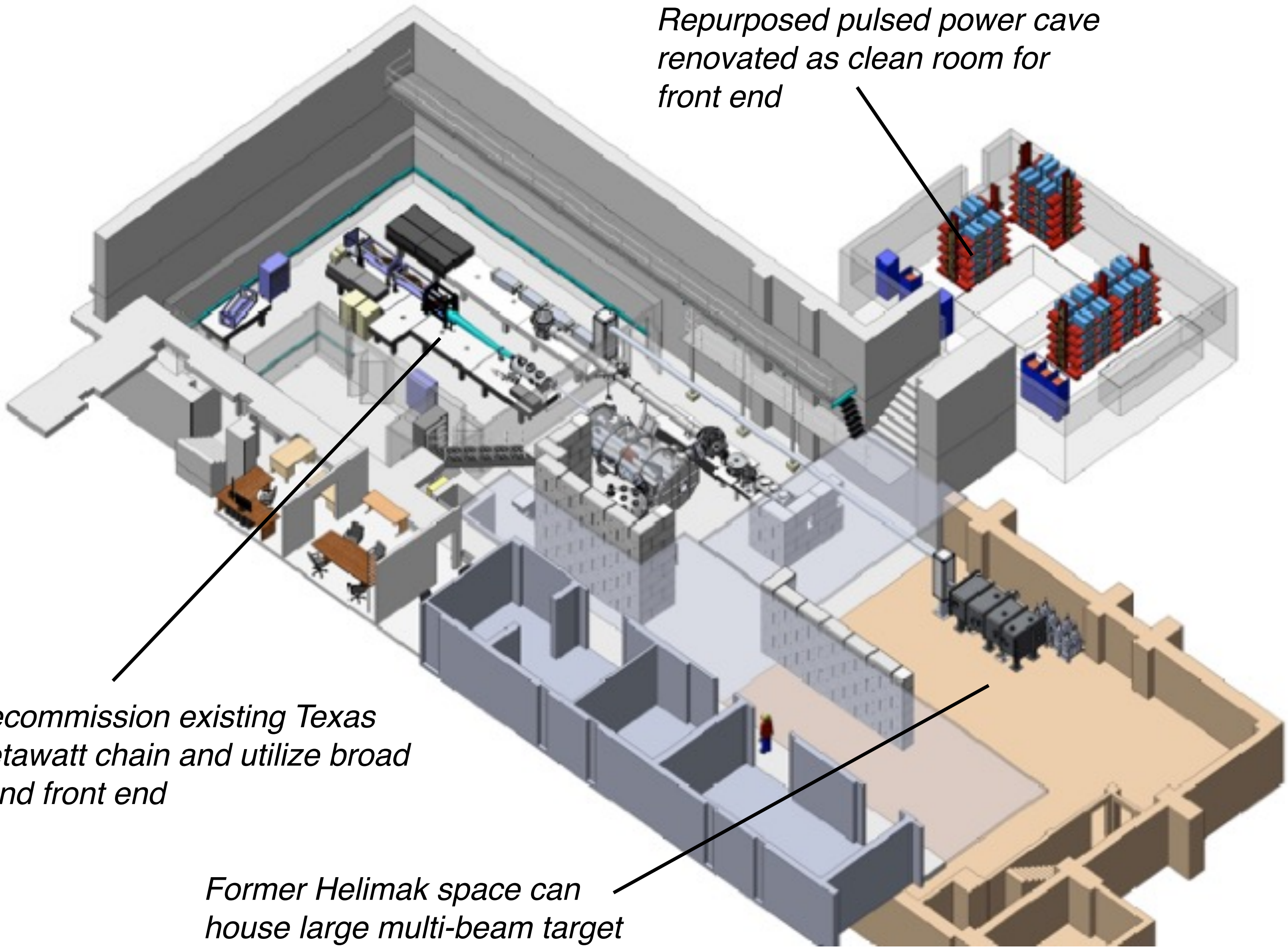


Existing Texas Petawatt footprint

Additional high bay space available for expanded laser beams

We can quickly and easily demo existing structures in the UT PMA high bay and renovate the space on a 1.5 year time scale

Repurposed pulsed power cave renovated as clean room for front end



Decommission existing Texas Petawatt chain and utilize broad band front end

Former Helimak space can house large multi-beam target chamber

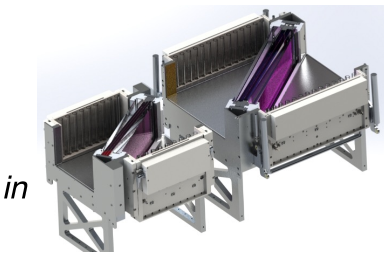
We are assessing the possibility of teaming with DOE FES and UT to build a joint, IFE research facility at the Texas Petawatt

LaserNetUS

FOCUSED ENERGY Inc.

TEXAS The University of Texas at Austin

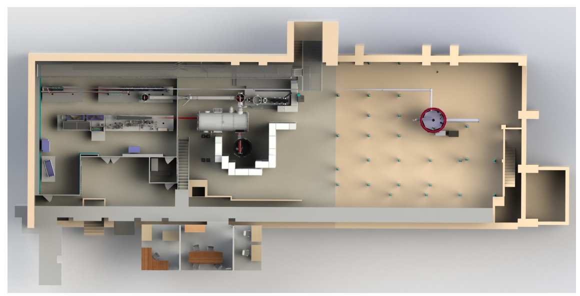
Power amplifiers are liquid-cooled, lamp pumped Nd:glass amps developed for L4 in ELI Beamlines



Prospective capability

- 4 beams firing @ 1 shot/3 min
  - Each can be operated in long pulse or fs-ps CPA mode
- LP Mode: 2.8 kJ per beam @ 527 nm
  - 2 – 15 ns, pulse shapeable
  - Broadband front end possible
- SP Mode: 1 kJ per beam
  - 400 fs – 10 ps
- 3 m diameter target chamber w/ flexible beam configurations

4 beam housed in expanded, 8000 sq. ft renovated high bay at UT in Austin



High Bay Renovations — *~ **$12M** renovation investment by UT (?)*

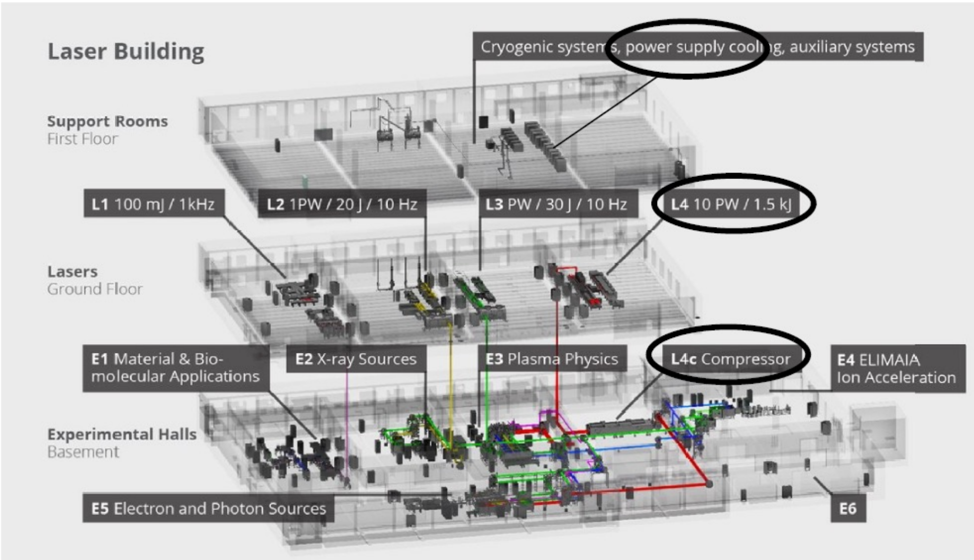
Facility Construction — *~ **$60M** construction investment by FE*

FE Experiments on IFE physics
- *~ 50% usage by FE (some UT discretionary time)*
- *~ 50% usage by outside users LaserNetUS or IFE Program peer review*

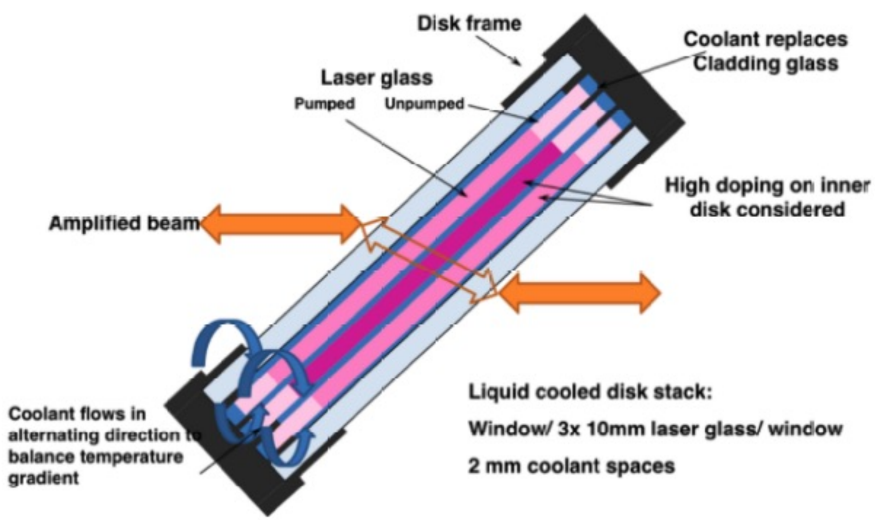
Operations DOE Funded (?)

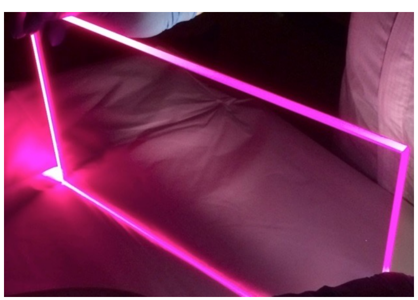
2021 2022 2023 2024 2025 2026

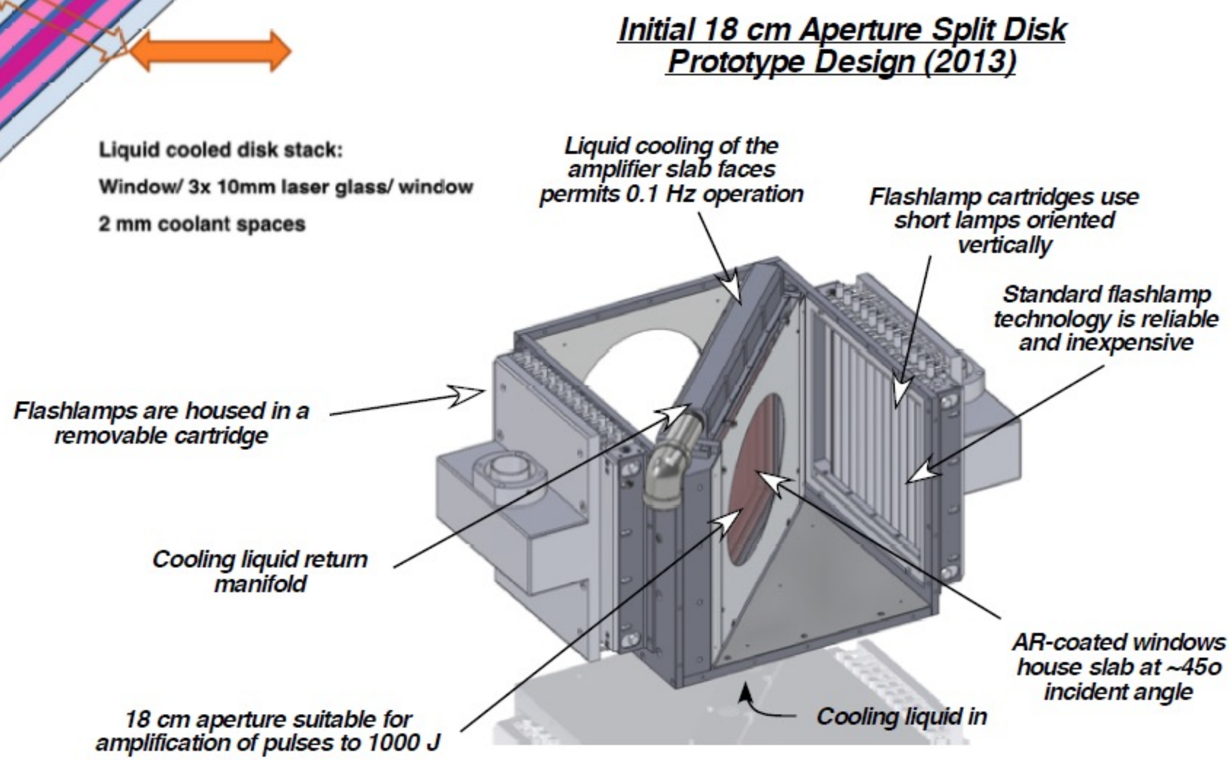
The L4 laser system is the highest energy laser deployed at the ELI-Beamlines facility



The UT IFE 4-beam laser will utilize liquid-cooled Nd:glass disk amplifier technology developed for L4



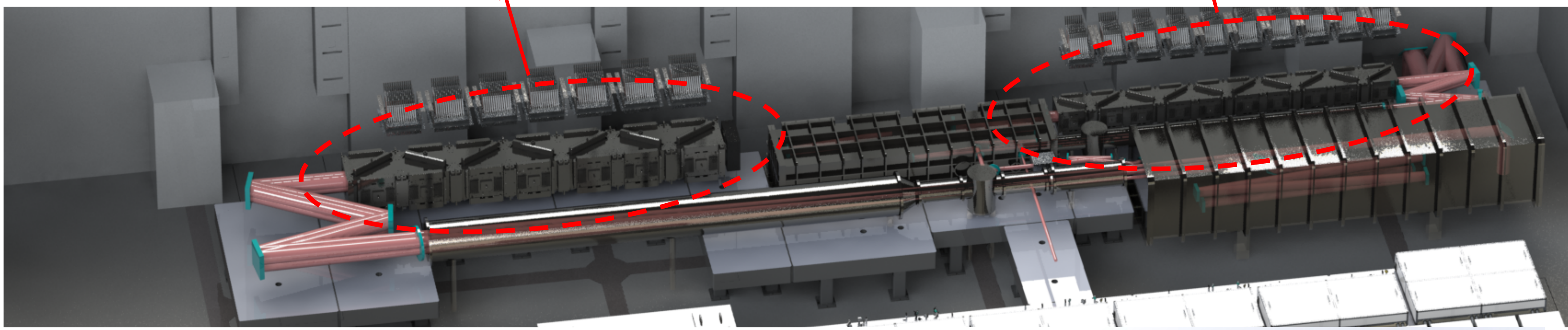


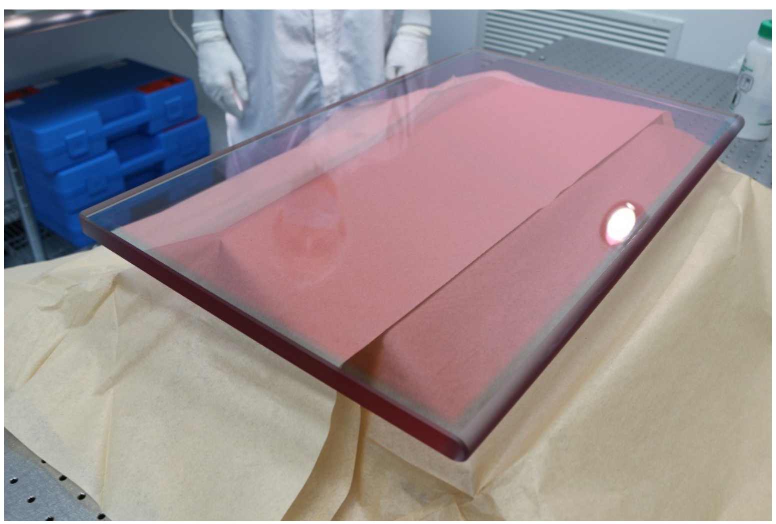


The split disk liquid cooled amplifiers have been deployed on L4 at up to 30 cm aperture

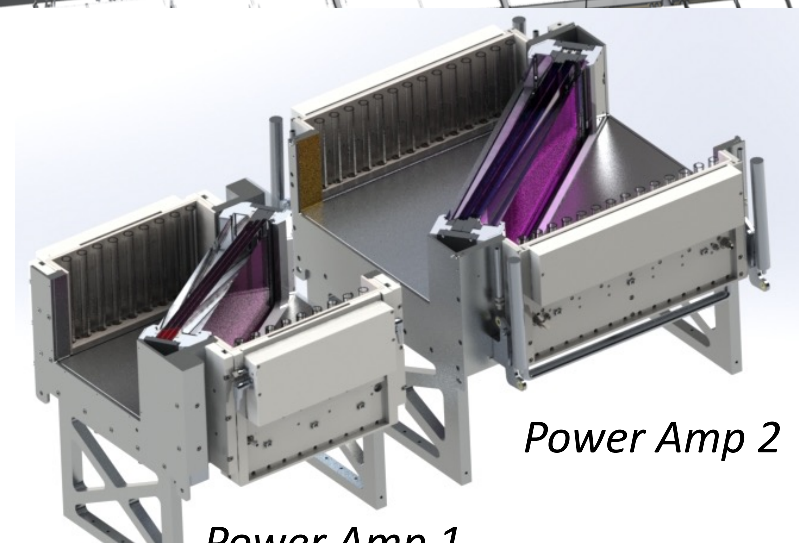
7x 30cm Aperture Power Amp 2 Modules (Cladded Nd:Phosphate)

10x 18cm Aperture Power Amp 1 Modules (Mix of Uncladded Nd: Phosphate and Nd:Silicate)





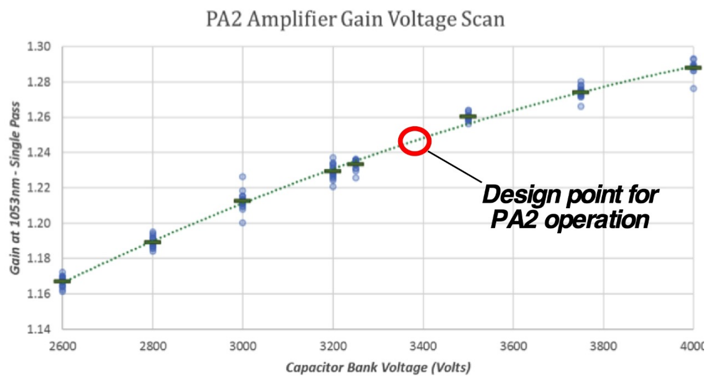
Cladded PA2 Slab



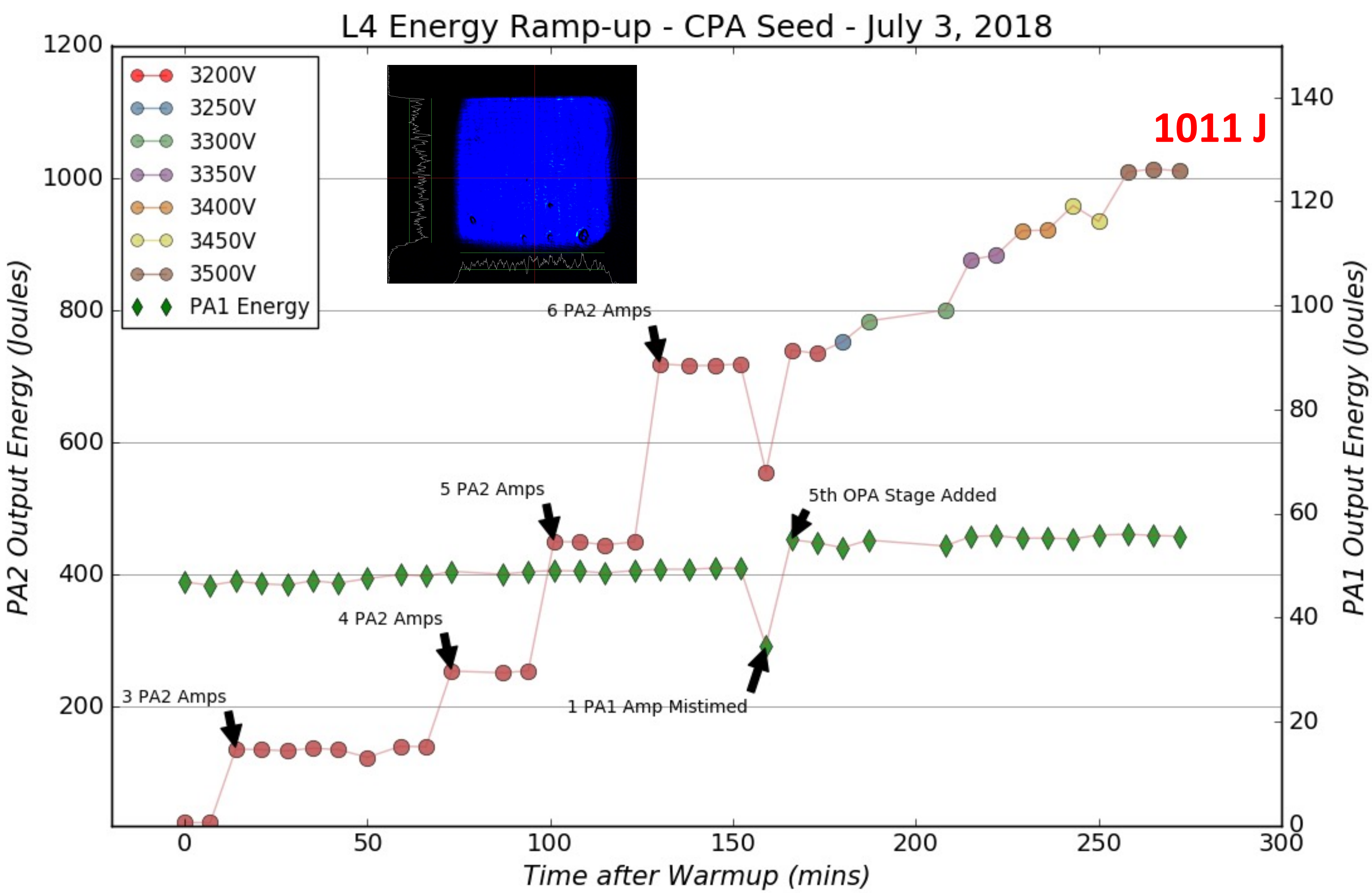
Power Amp 2

Power Amp 1

Power Amp2 has 30 cm aperture modules with Nd:glass and is designed for easy inspection with 5 kV power supplies



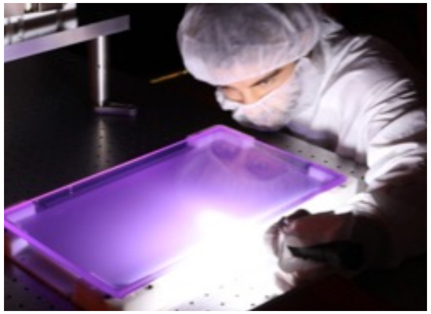
1 kJ energies were achieved with the broad band CPA seed at one shot/5 min

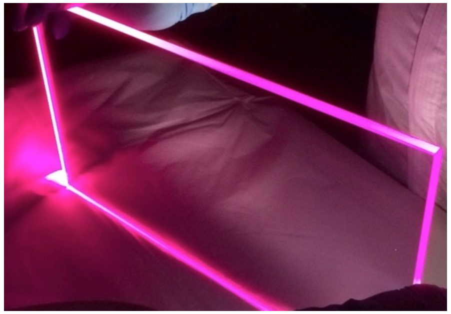


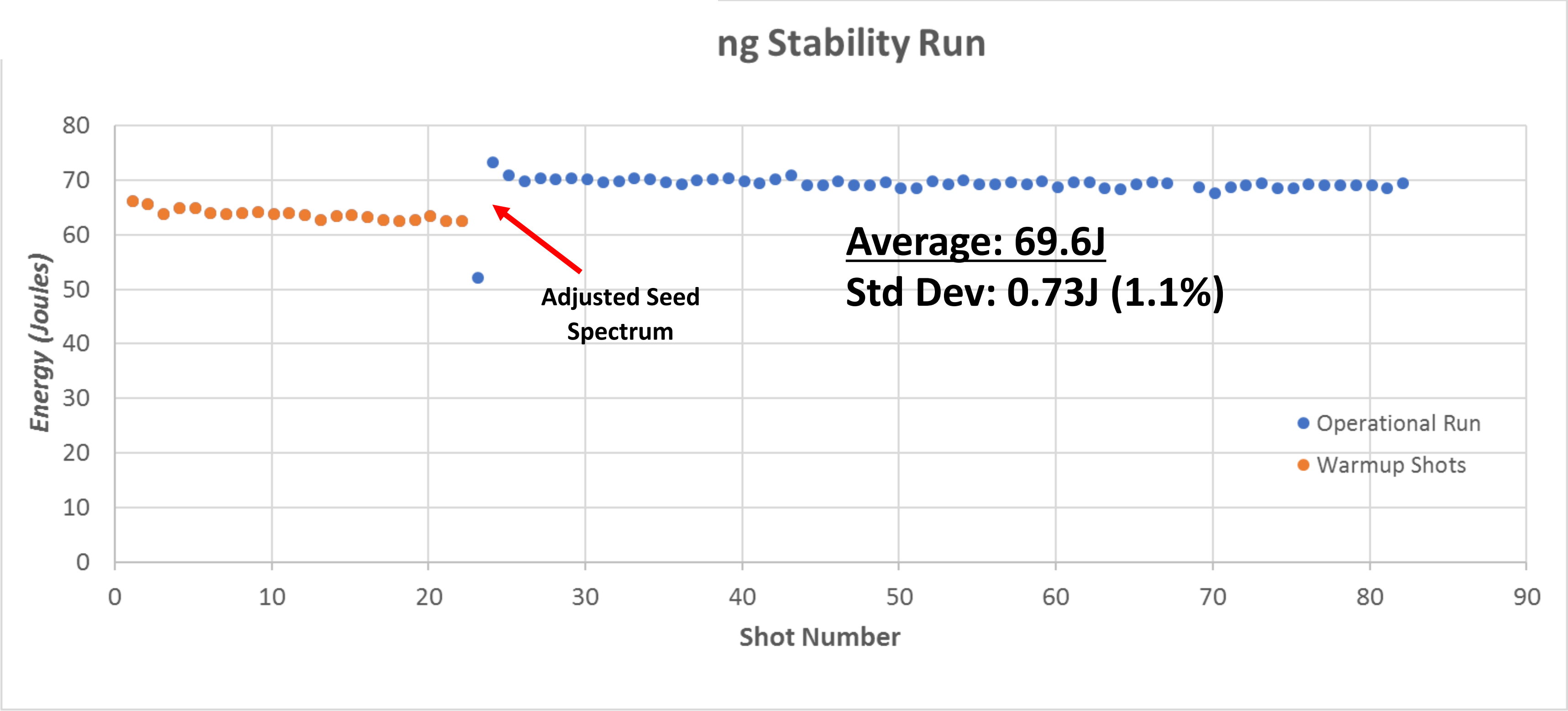
Power Amp 1 shows excellent energy stability with 70 J output easily attained daily

NATIONAL ENERGETICS

- *OPA Seed Energy is 3.3J (up to 4J available)*
- *9 out of 10 Amplifiers typically used*
- *23% phosphate, 77% silicate Nd:glass*





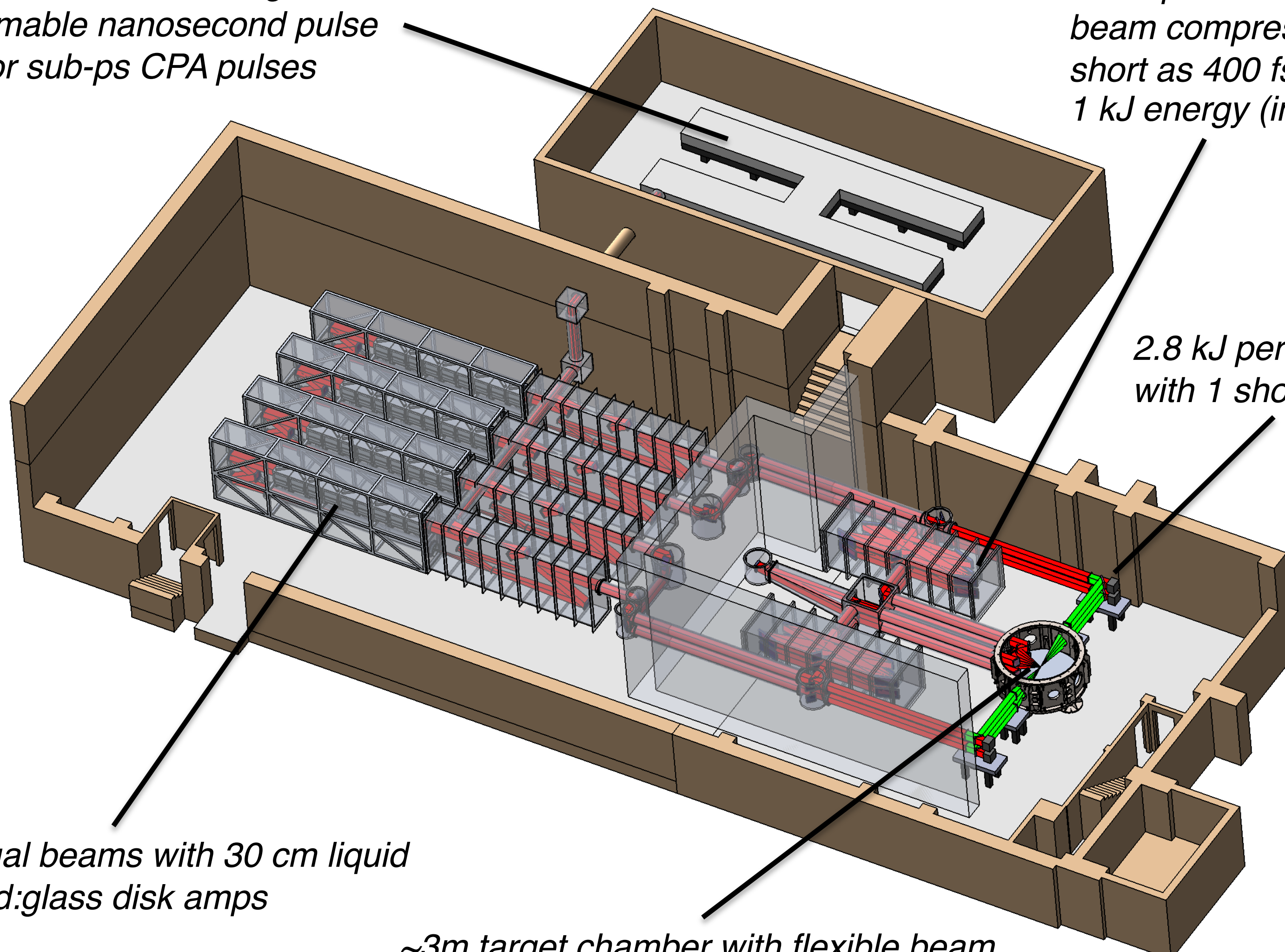


We have put together a conceptual design for a 4-beam facility with each beam capable of long and short pulse modes

4-beam front end delivering programmable nanosecond pulse shapes or sub-ps CPA pulses

Short pulse mode in each beam compressed to as short as 400 fs and with up to 1 kJ energy (in ps pulses)

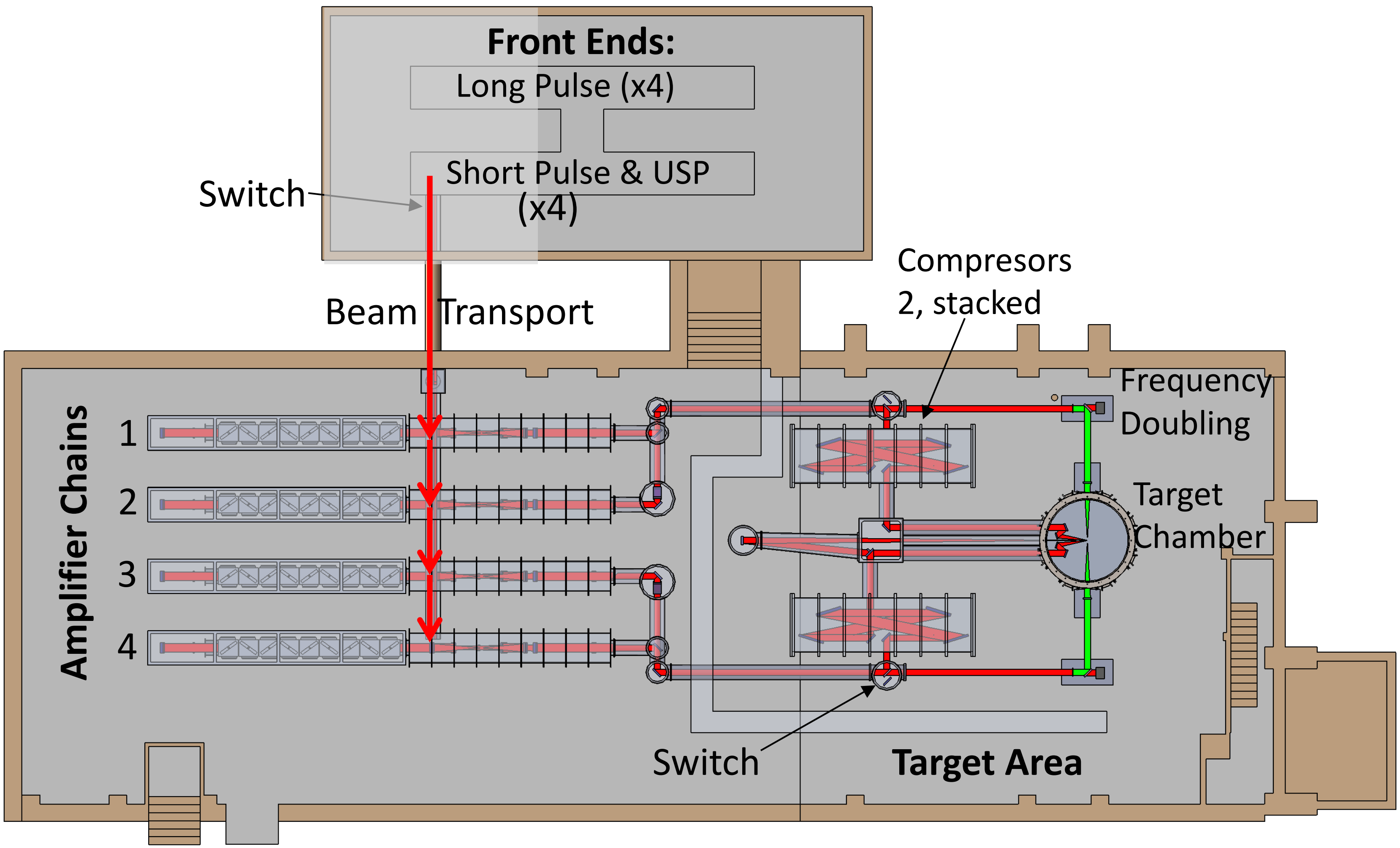
2.8 kJ per beam at 2ω with 1 shot/3 min rep. rate



4 individual beams with 30 cm liquid cooled Nd:glass disk amps

~3m target chamber with flexible beam configurations including short and long pulses from all 4 beams

The proposed layout includes four amplified beamlines utilizing liquid-cooled 30 cm Nd:glass disk amps



Each beam will be able to run in either pulse shaped nanosecond mode or sub-picosecond CPA mode

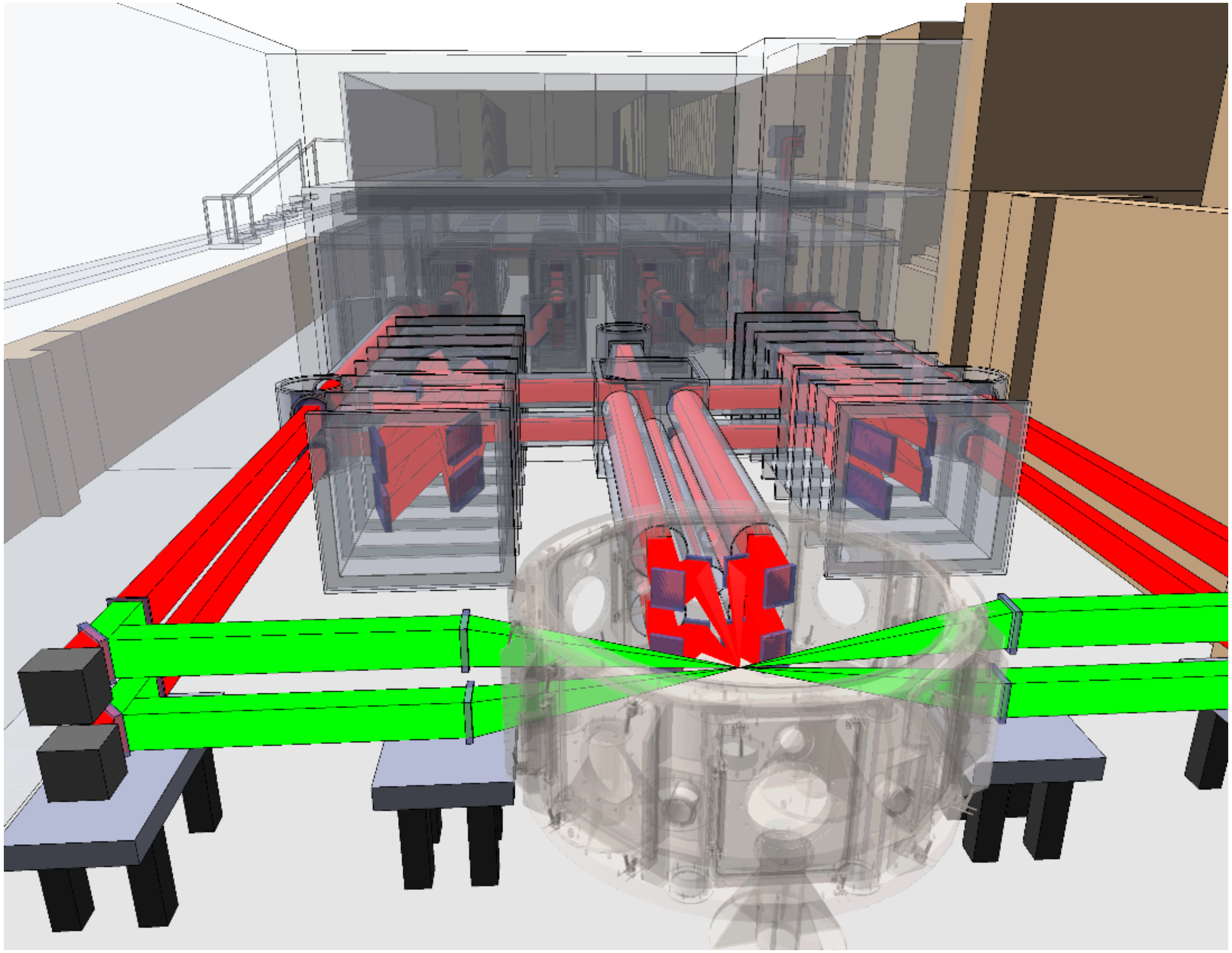
Beam configured in nanosecond pulse mode

Pulse Duration	Max Energy @ 1054nm	B-Integral	FE Seed Energy
1 ns	500 J	1	0.2 J
2 ns	900 J	1	0.5 J
3 ns	1.2 kJ	1	0.7 J
5 ns	1.7 kJ	1	1.5 J
10 ns	3 kJ	1	5 J
10 ns	4 kJ	1.7	15 J
20 ns?	4.3 kJ	1	25 J

Beam configured in short pulse mode

Pulse Duration	Max Energy @ 1054nm	Fluence on grating
350 fs	450 J	0.20 J/cm^2
500 fs	475 J	0.21 J/cm^2
700 fs	515 J	0.23 J/cm^2
1 ps	560 J	0.25 J/cm^2
2 ps	650 J	0.29 J/cm^2
3 ps	720 J	0.32 J/cm^2
4 ps	760 J	0.34 J/cm^2
5 ps	810 J	0.36 J/cm^2
10 ps	900 J*	0.4 J/cm^2

There are many possible target chamber configurations, which can accommodate a diverse range of experiments

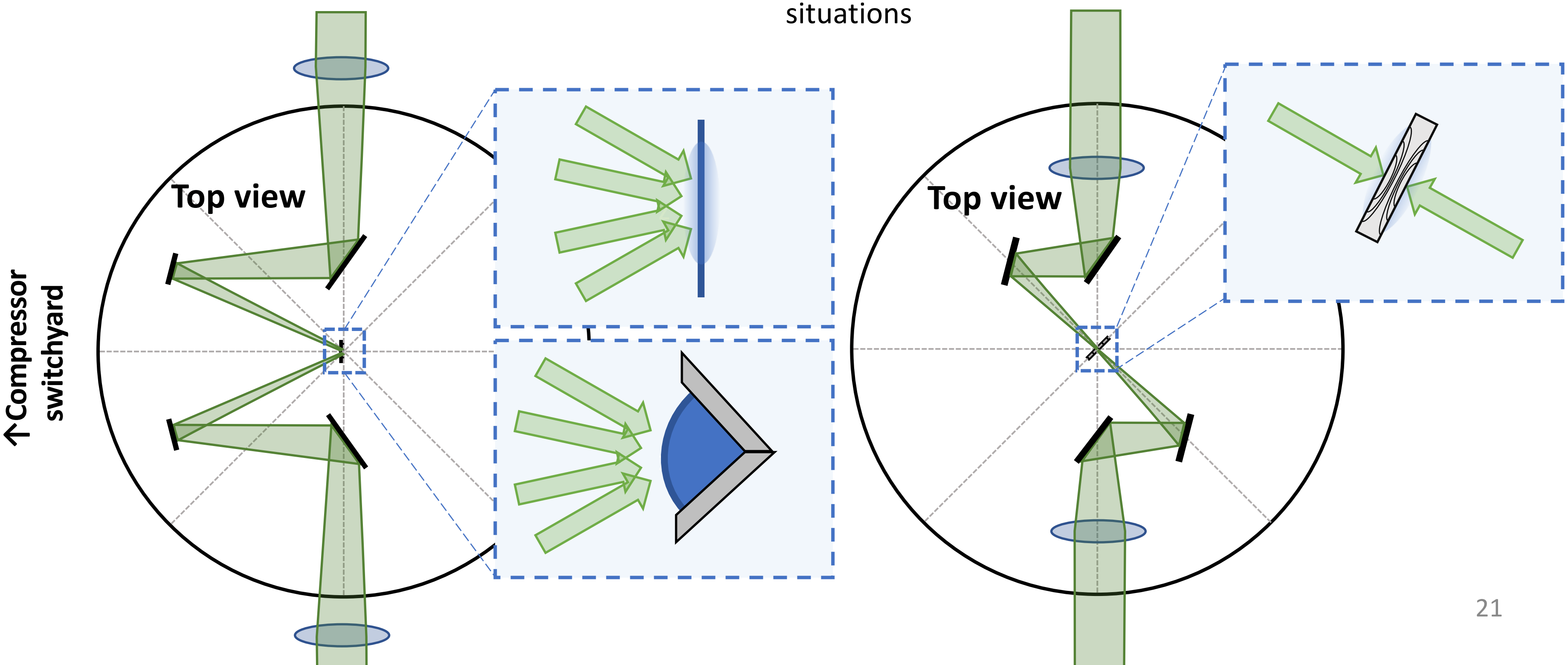


The beams in long pulse mode have greater flexibility in beam placement

Beam	Short pulse
Spot size	50 – 100 um
Intensity, I_0	Up to ~ 2×10^{16} W/cm^2 per beam
θ_{target}	$15°\ - 45°$, front & back

Experimental studies

- Study of LPI and CBET effects in 2ω and 3ω drive beams
  - LPI in in hot spot and fast ignition relevant drive pulses
  - Explore LPI mitigating techniques
  - Study CBET in multiple overlapped beams
- Hydro drive pressure, efficiency and instabilities
  - High repetition rate studies of direct-drive relevant situations

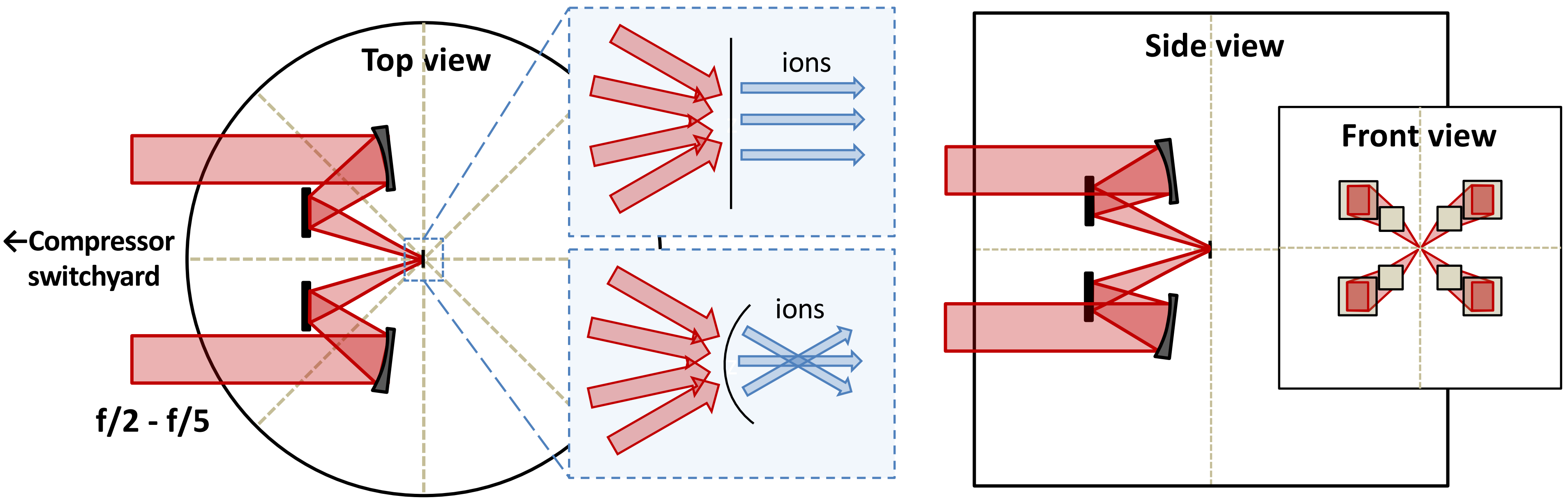


We are exploring various f/#'s for focusing the beams in sub-ps CPA mode

Beam	Short pulse
Spot size	5 – 100 um on target
Intensity, I_0	Up to ~ 2×10^{21} W/cm^2 per beam
θ_{target}	$15^\circ - 45^\circ$

<u>Experimental studies</u>

- Study of proton acceleration efficiency
  - multi-kJ picosecond drive pulse scaling
  - pulse duration scaling
  - overlapping multiple picosecond beams effects
- Study of hot electron generation
  - Conversion efficiency at high drive energies
  - Hot electron transport (cone in shell targets)



We will attempt to have first light into a target chamber in 2025

	Activity Name	Duration (Work Days)	Start Date	Finish Date
1	**Rough Design (qty, footprint)...**	140.00	11/2/21	5/16/22
10	Completion of rough CDR, key stakeholder meeting	0.00	5/16/22	5/16/22
11	**Detailed design...**	285.00	5/17/22	6/19/23
21	Completion of detailed CDR, technical meeting	0.00	11/25/22	11/25/22
22	**Procurement...**	660.00	5/17/22	11/25/24
38	**Component construction @ separate facility...**	392.00	5/29/23	11/26/24
44	**Renovation...**	408.00	10/10/22	5/1/24
48	Front End cleanroom complete	0.00	2/1/24	2/1/24
49	Highbay renovation complete	0.00	5/1/24	5/1/24
50	**Laser Build at Facility...**	364.00	2/2/24	6/25/25
62	First Light	0.00	2/3/25	2/3/25
63	**Testing**	20.00	6/12/25	7/9/25

We held a workshop on 10 February virtual/in person in Austin to solicit community input on the desired facility capabilities

Appendix A. Agenda

Time		Who	Item
10:00 AM	P	Juan Fernández, ASE	Welcome, charge and announcements
10:05 AM	P	Jennifer Lyon Gardner, UTA Deputy VP for Research	UT perspective
10:10 AM	P	Kramer Akli, DOE FES	Workshop context and LaserNetUS
10:30 AM	P	Todd Ditmire, UTA and FE	Rationale & scope for a joint UTA/FE laser facility
10:45 AM	P	Markus Roth, TUD and FE	Selected science & technical issues motivating new facility
11:15 AM	P	Sandi Bruce, UTA	Envisioned facility and capabilities ("Version A")
11:45 AM	P	Carly Anderson, PM	Investor's perspective
11:55 AM	P	Moderator: Fernández	Question and Answer session
12:10 PM			Break; advocate presentation order on Zoom shared
12:30 PM	P	Moderator: Barnes Presentations: participants Discussion: participants	Specific science issues & capability requirement Advocate presentation, 5 Min; discussion, 5 Min Order preassigned
2:30 PM			"Lunch" Break; organizers incorporate community feedback, facility "version B" generated
3:15 PM	P		Facility version B shared on Zoom; breakout session location and participants info e-mailed
3:30 PM	C	Moderators: TBD Participant breakout: TBD	Breakout groups edit and flesh out new requested capabilities in version B
5:00 PM			Break; moderators prepare summary
5:20 PM	P	Moderators	Breakout session moderators share a 5 Min summary of their deliberations
5:45 PM	P	Juan Fernández	Closing comments, logistics for comments on written workshop summary & facility version C
6:00 PM			Adjourn

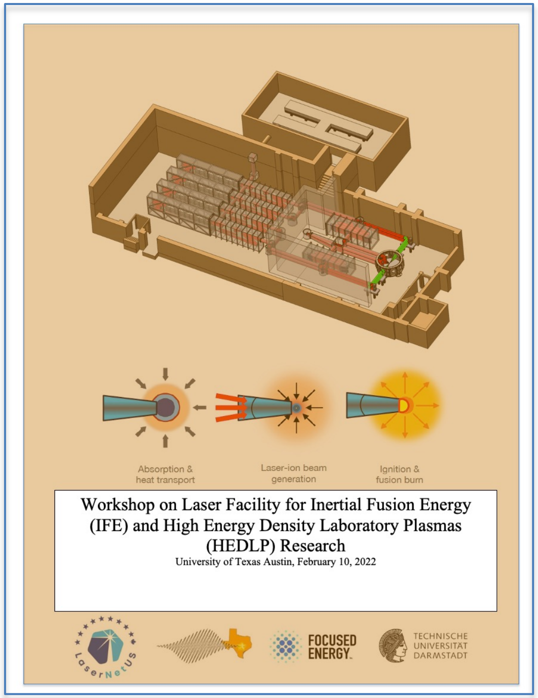
Workshop Chairs were Juan Fernandez and Cris Barnes

The workshop was attended by 88 people, 20 in person with 19 community "idea" contribution talks

Appendix C: List of community presenters

1. Christine Labaune (Ecole Polytechnique), Incoherent beams for LPI [in Europe, going first at 12:30 CST / 19:30 CET]
2. Cameron Geddes (LBL), Proton acceleration experimental possibilities
3. Farhat Beg (UCSD), Proton Fast Ignition
4. Brian Albright (LANL), high-power laser-based ion acceleration for ion fast ignition
5. Thomas Schenkel (LBL), Novel Materials Synthesis techniques
6. Alexander Thomas (U Michigan), Machine Learning at 1 shot every 3 minutes
7. Neal Alexander (GA), IFE technology integrations (tracking targets, measuring cryo layers in flight)
8. Neal Alexander (GA), Secondary radiation sources of heavy ions for single event effects (SEE)
9. Brian Albright (LANL), development of high resolution, high-brightness, MeV x-ray radiography for inertial fusion (and other!) applications
10. Thomas Schenkel (LBL), Secondary Beam Use
11. Sasi Palaniyappan (LANL), spatial and temporal pulse constraints for ion acceleration
12. Sophia Malko (Princeton), importance of ion stopping power for IFE
13. Cameron Geddes (LBL), Hydrodynamics and turbulence
14. Carolyn Kuranz (U Michigan), planar hydro / astrophysics
15. John Kline (LANL), Symmetry / hydro
16. Mark Schmidt (LANL) direct drive implosions
17. David Montgomery (LANL), LPI
18. Bedros Afeyan (Polymath), STUD [at 2:00 pm CST please]
19. Bob Kirkwood (LLNL) Counter-propagating long pulse for LPI [Unfortunately, at this point we ran out of time]
20. Vladimir Tikhonchuk (U Bordeaux), ELI Beamlines

The workshop has generated a report that has been circulated to the participants and is now ready for release



Desired capabilities matrix

Topic	LPI & Plasma Optics	Rad-hydro	RLP	Basic	Applications
Capability					
Laser					
No. of beams	2 -- 4, 3 same plane	≥ 2	≥ 2	WDM: 3	≥ 2
Wavelength l_0 (mm)	1, 0.5, 0.35	0.5, 0.35	1, 0.5		
D l_0 (nm)	≥ 1	≥ 1			
Beam-beam delay (ns)		100	100	100	100
Beam Sync	1 ps		0.1 ps	1 ps	0.1 ps
Bandwidth (THz)	10		12		
High Rep rate?	Yes	Yes	Yes	Yes	Yes
Long pulse (ns)	0.1 -- 10	0.1 -- 10			
LP dynamic range		≥ 100		≥ 100	
LP time shaping		Arbitrary			
LP beam energy (J, 1ns)	≥ 1000	≥ 1000			
LP focal spot (with phase plate)	Variable	Variable			
LP pointing stability		25 μm			
Short pulse (ps)	1 -- 10		0.15 -- 10	0.15 -- 10	0.15 -- 10
SP contrast @ -0.5 ns & -5 ps			10^{12}, 10^{8}	10^{12}, 10^{8}	Radiography: 10^{12}, 10^{8}
SP time shaping & tolerance			Yes, ≤ 0.15 ps		
SP focus intensity spatial shaping			Yes		Yes
Intensity (W/cm^2)	≤2×10^{15} ≤10^{16} DL spots	≤ 2×10^{15} 1ns ≤ 10^{17} 0.1ns	10^{19} -- 10^{23} 10^{21} typical		
SP beam energy in 1ps pulse (J)			1000		1000
SP pointing stability			~ spot size	~ spot size	~ spot size
f/number	4, 8, 20		≈ 2, 100		
Front-end, other	STUD (Stiletto)	SSD			
Polarization	L	L	L, C	L	L
Pol. control	Par., Perp.	Par., Perp.	Par., Perp.		Par., Perp.
DL focal spots?	1,2, many; co-linear, side by side		Yes	Yes	Yes
Beam geometry					
Crossing angle (deg)	≈ 0 -- ≈ 180	≈ 0 -- ≈ 180	≈ 0, ≈ 90	≈ 0, ≈ 90	≈ 0, ≈ 90
Radiation shielding			Yes	Yes	Yes
Other laser probes					
250nm probe laser	10 J, few ns for TS				
Ti:S 40 fs, 3-30 J		Yes	Yes	Yes	Yes

After further consideration, there are some recommendations and actions:

- The UTA/FE design team should carefully consider the community capability request motivated by this workshop and attempt to implement what is feasible into their project.
- They should work with the entire IFE community on a Roadmap for science and technology development.
- After the Basic Research Needs Workshop scheduled for May, run a workshop (or several separate ones) for the priority research directions on standard setups or experimental platforms for key first experiments that can drive target area design
- T-STAR team needs to understand and be involved in discussion about common diagnostic interface (as opposed to DIM/TIM…) for LaserNetUS.
- Advocate for FES funding for key science diagnostics needed by these PRDs, able to be used at T-STAR as well as other LaserNetUS facilities.
- T-STAR team should get involved with the LaserNetUS working subcommittees. Consider promoting national workshops for each subcommittee on common needs.
- Encourage LaserNetUS to consider having a subcommittee for target fab.